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Ciaccio et al.

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(54) **BATTERY AND CAPACITOR ASSEMBLY FOR A VEHICLE AND A METHOD FOR HEATING AND COOLING THE BATTERY AND CAPACITOR ASSEMBLY**

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H01M 50/20	(2021.01)

(Continued)

(52) **U.S. Cl.**

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(Continued)

(58) **Field of Classification Search**

CPC H01M 10/60–667; H01M 10/05–0525; H01M 10/42; H01M 10/48;

(Continued)

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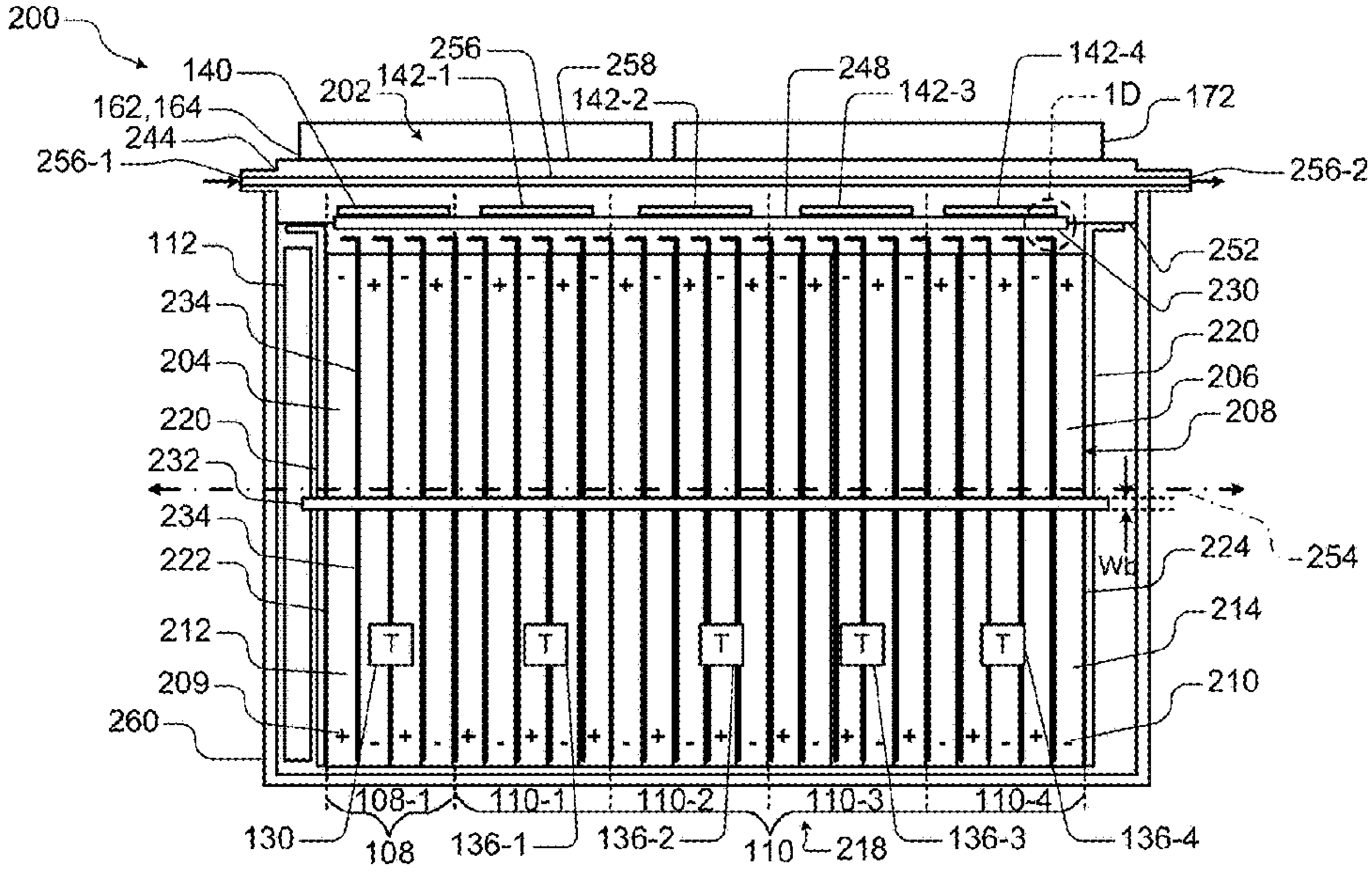
Assistant Examiner — Jacob Buchanan

(57) **ABSTRACT**

A battery and capacitor assembly for a hybrid vehicle includes a plurality of battery cells, a plurality of capacitor cells, a cooling plate, a pair of end brackets, and a housing. The plurality of capacitor cells are arranged adjacent to the plurality of battery cells such that the plurality of battery cells and the plurality of capacitor cells form a cell stack. The pair of end brackets are disposed at opposite ends of the cell stack and are attached to the cooling plate. The pair of end brackets compress the plurality of battery cells and the plurality of capacitor cells. The housing is attached to the cooling plate and encloses the cell stack and the pair of end brackets.

26 Claims, 6 Drawing Sheets



Related U.S. Application Data

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(51) **Int. Cl.**

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B60L 58/26	(2019.01)
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H01G 11/18	(2013.01)
H01G 11/82	(2013.01)
H01M 10/052	(2010.01)
H01M 10/613	(2014.01)
H01M 10/615	(2014.01)
H01M 10/617	(2014.01)
H01M 10/625	(2014.01)
H01M 10/647	(2014.01)
H01M 10/6555	(2014.01)
H01M 10/6556	(2014.01)
H01M 10/6572	(2014.01)
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B60L 58/15	(2019.01)
H01M 10/42	(2006.01)
H01M 10/48	(2006.01)
B60L 7/10	(2006.01)

(52) **U.S. Cl.**

CPC ***B60L 58/26*** (2019.02); ***B60L 58/27*** (2019.02); ***H01G 11/08*** (2013.01); ***H01G 11/18*** (2013.01); ***H01G 11/82*** (2013.01); ***H01M 10/0481*** (2013.01); ***H01M 10/052*** (2013.01); ***H01M 10/4257*** (2013.01); ***H01M 10/4264*** (2013.01); ***H01M 10/482*** (2013.01); ***H01M 10/486*** (2013.01); ***H01M 10/613*** (2015.04); ***H01M 10/615*** (2015.04); ***H01M 10/617*** (2015.04); ***H01M 10/625*** (2015.04); ***H01M 10/647*** (2015.04); ***H01M 10/6555*** (2015.04); ***H01M 10/6556*** (2015.04); ***H01M 16/00*** (2013.01); ***H01M 50/20*** (2021.01); *B60L 7/10* (2013.01); *B60L 2240/525* (2013.01); *B60L 2240/526* (2013.01); *B60L 2240/527* (2013.01); *B60L 2240/545* (2013.01); *B60L 2240/547* (2013.01); *B60L 2240/549* (2013.01); *H01M 2010/4271* (2013.01); *H01M 2200/20* (2013.01); *H01M 2220/20* (2013.01); *Y02E 60/10* (2013.01); *Y02T 10/70* (2013.01)

(58) **Field of Classification Search**

CPC .. H01G 11/00–12; H01G 11/18; H01G 11/78; H01G 11/82; B60L 58/26–27; B60L 50/60

See application file for complete search history.

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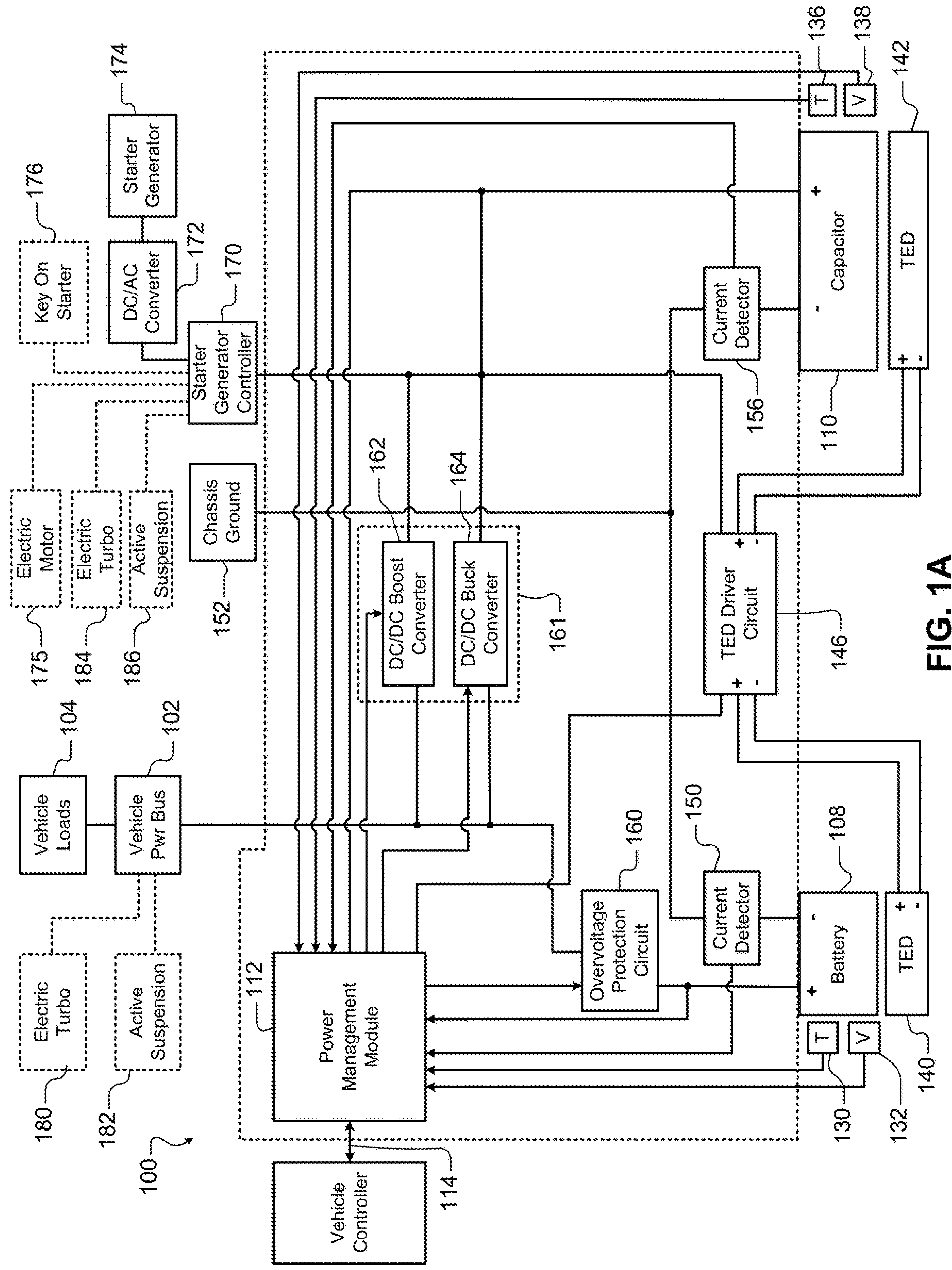

Vehicle Loads
104
Vehicle Pwr Bus
102
Electric Turbo
180
Active Suspension
182
100
Vehicle Controller
114
Power Management Module
112
Electric Motor
175
Electric Turbo
184
Active Suspension
186
Key On Starter
176
Starter Generator
174
DC/AC Converter
172
Starter Generator Controller
170
Chassis Ground
152
DC/DC Boost Converter
162
DC/DC Buck Converter
164
161
Overvoltage Protection Circuit
160
Current Detector
150
Current Detector
156
TED Driver Circuit
146
Battery
108
Capacitor
110
TED
140
TED
142
T
130
V
132
T
136
V
138
+
-

FIG. 1A

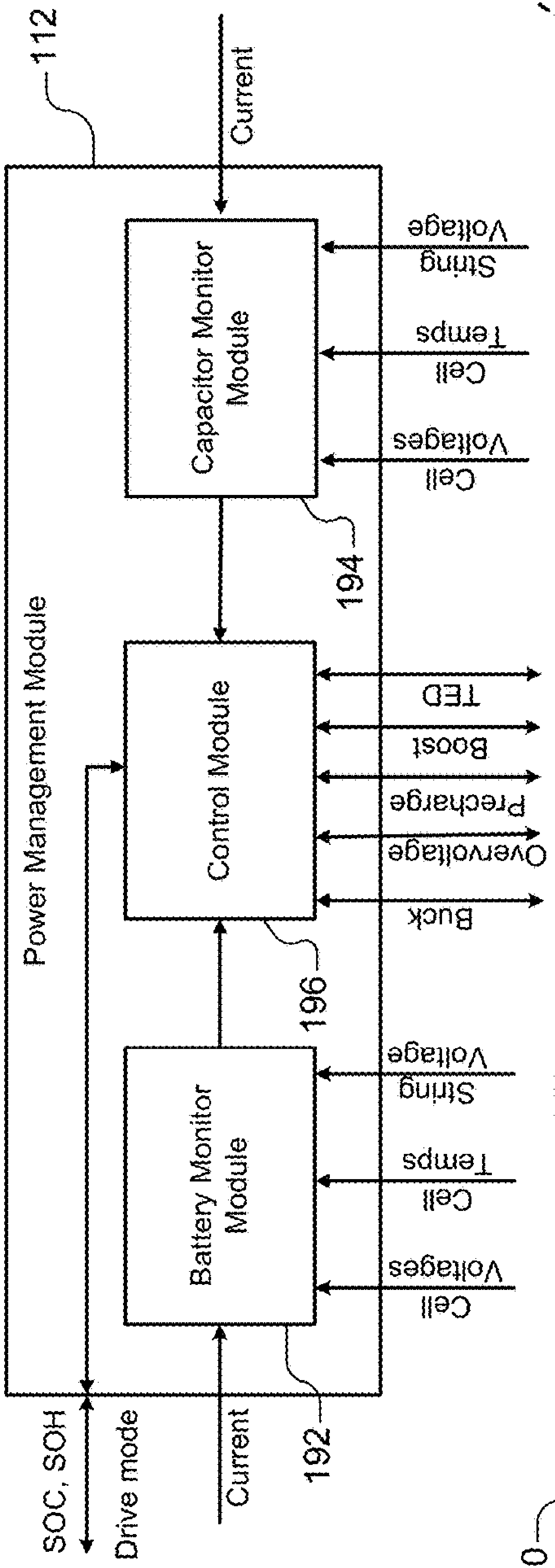


FIG. 1B

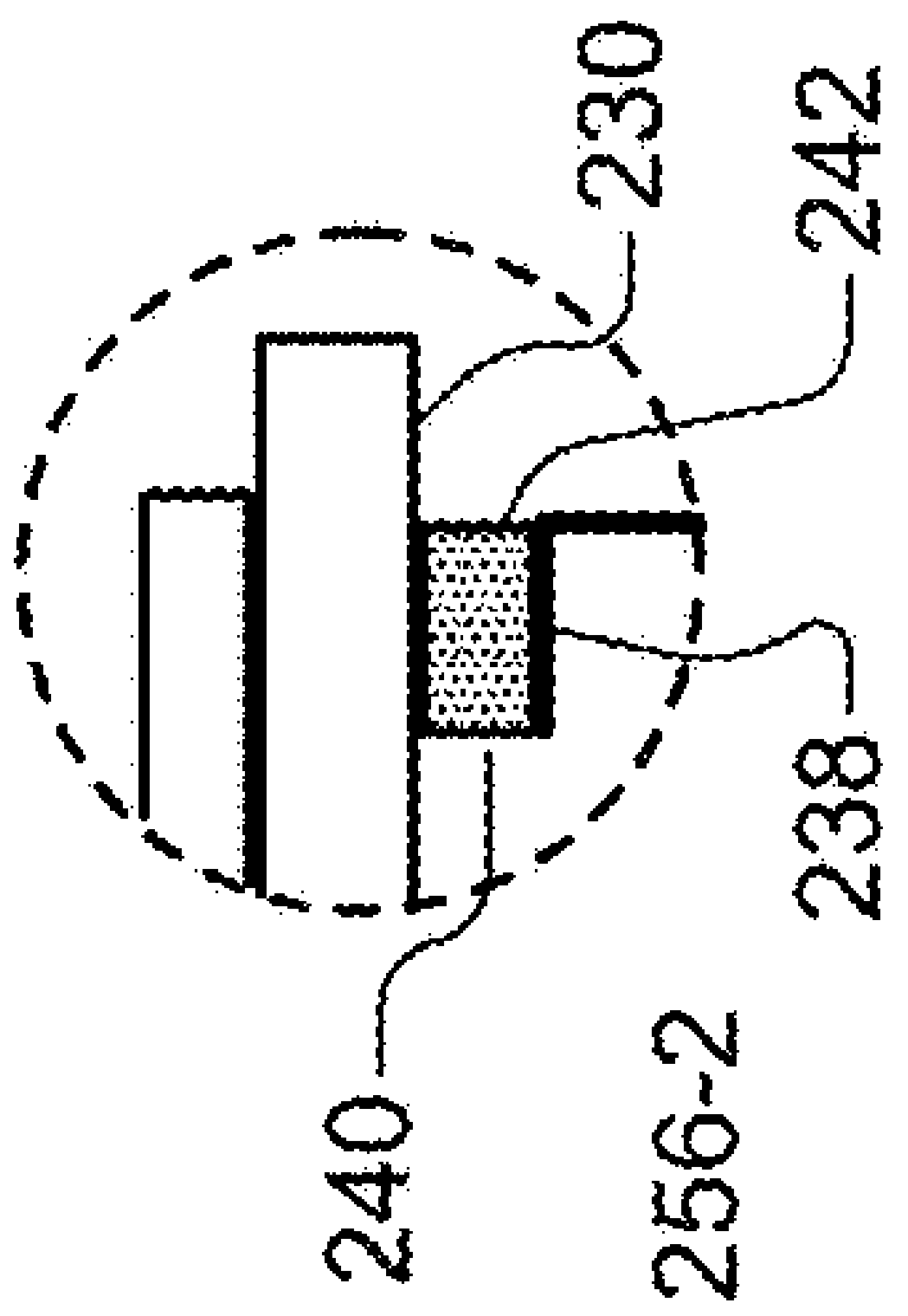


FIG. 1D

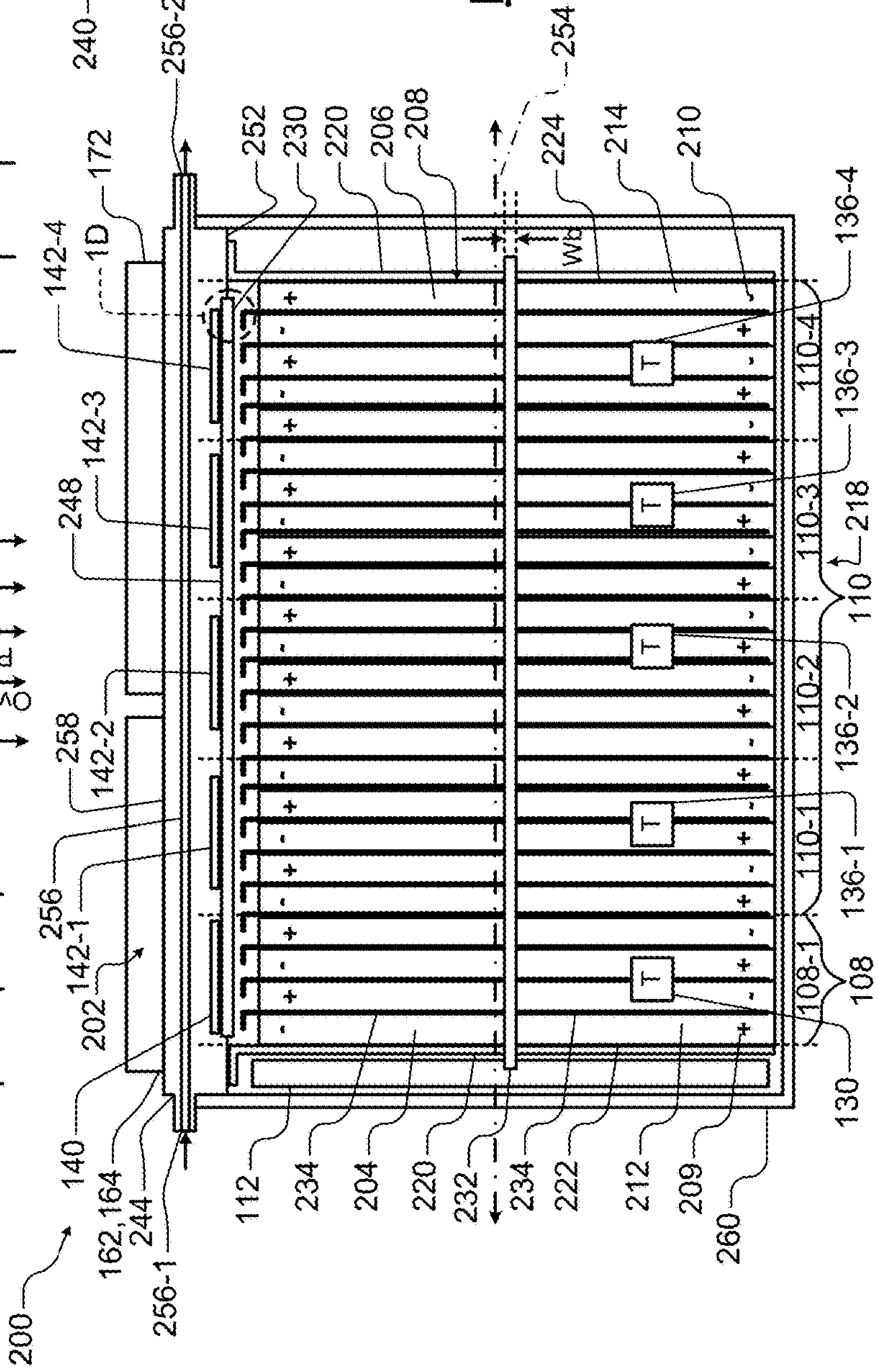
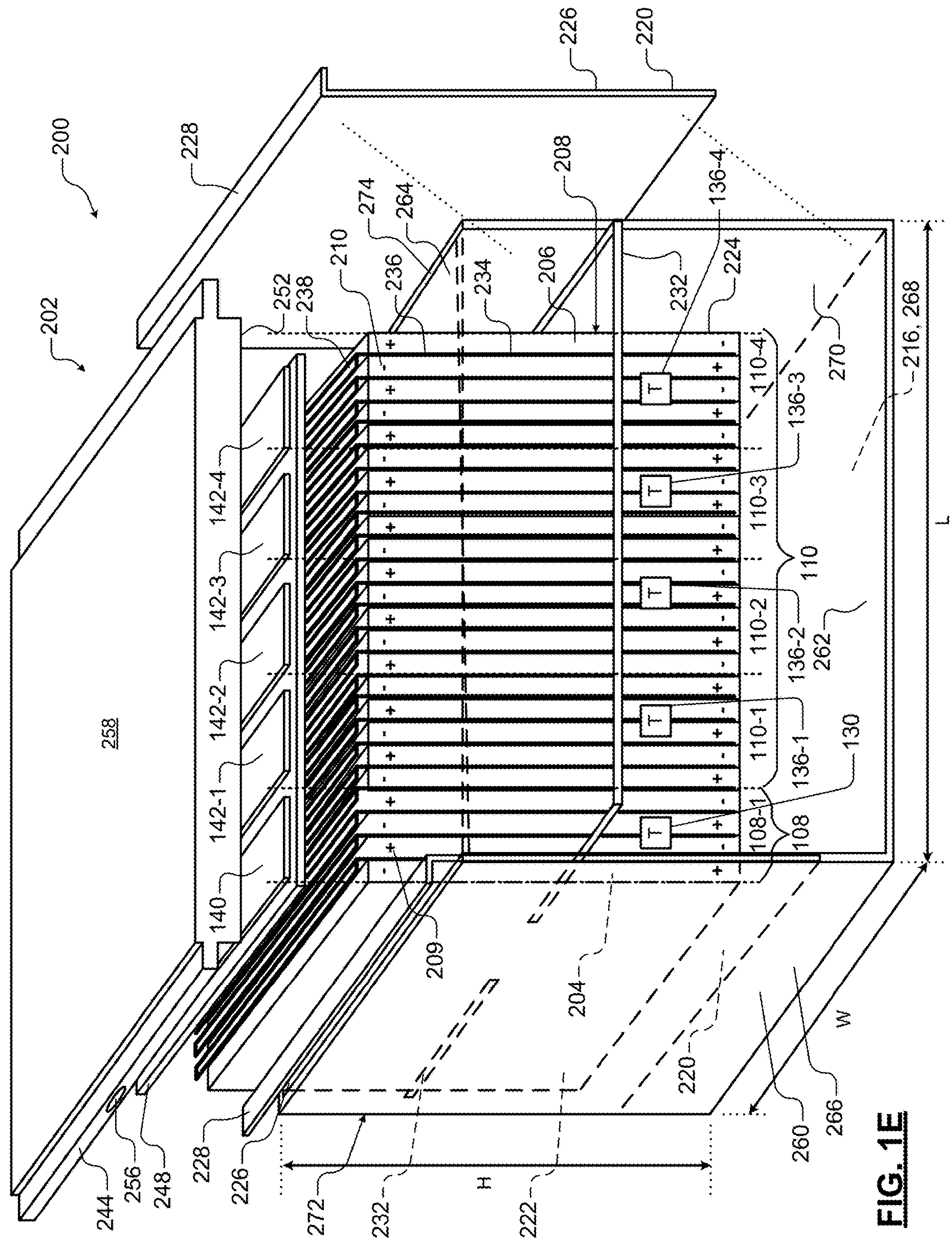


FIG. 1C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202
228
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136-4
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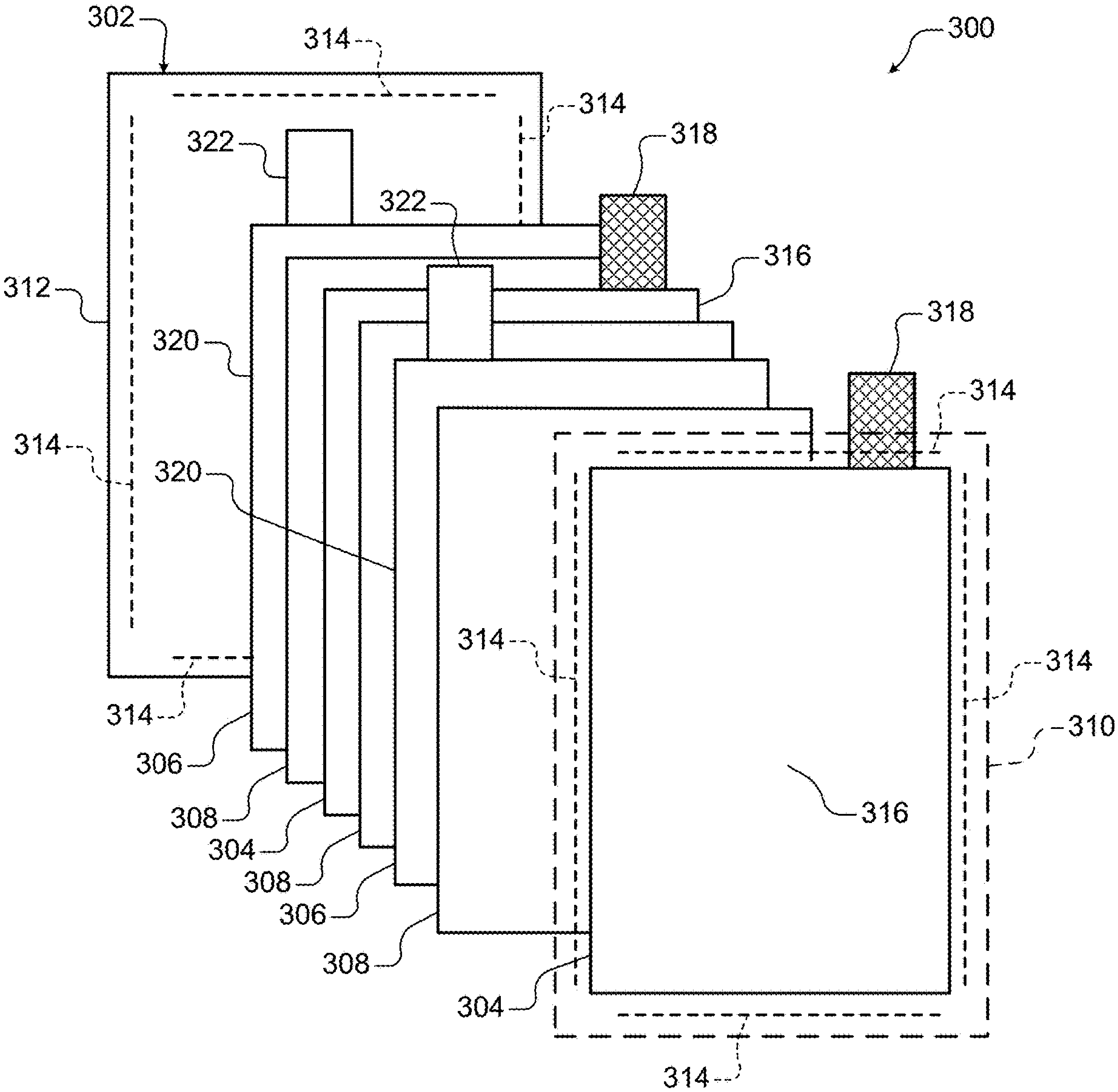
142-2
142-1
140
110-4
110-3
110-2
110-1
110
136-3
136-2
136-1
130
108-1
108
270
216, 268
262
L
T
+
-
209
204
220
W
260
266
244
256
248
228
226
272
232
H
222

FIG. 1E


300
302
314
314
322
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316
314
306
308
304
308
306
308
304
314

FIG. 1F

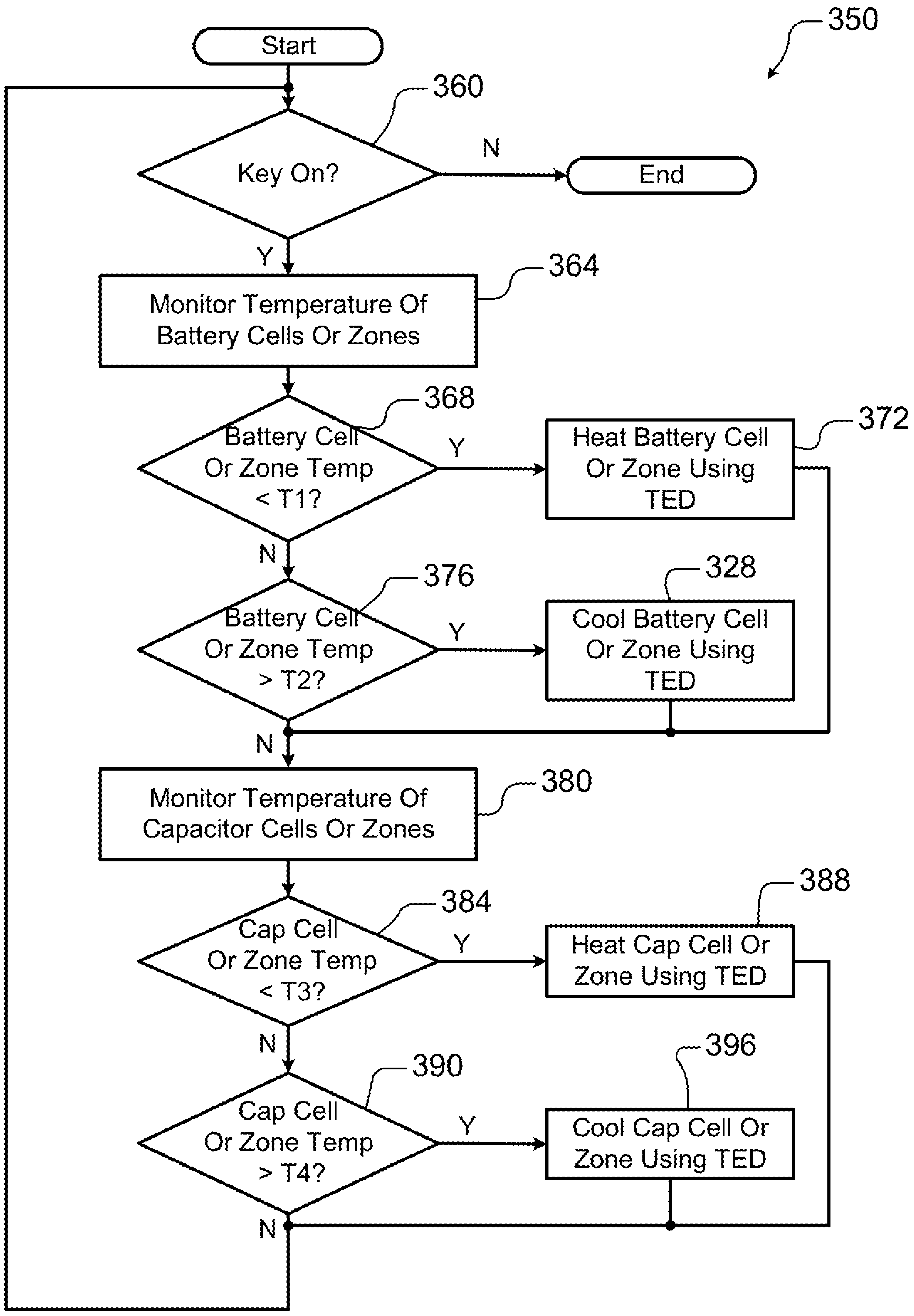
350
Start
360
Key On?
N
End
Y
364
Monitor Temperature Of Battery Cells Or Zones
368
Battery Cell Or Zone Temp < T1?
Y
Heat Battery Cell Or Zone Using TED
372
N
376
Battery Cell Or Zone Temp > T2?
Y
328
Cool Battery Cell Or Zone Using TED
N
Monitor Temperature Of Capacitor Cells Or Zones
380
384
Cap Cell Or Zone Temp < T3?
Y
388
Heat Cap Cell Or Zone Using TED
N
390
Cap Cell Or Zone Temp > T4?
Y
396
Cool Cap Cell Or Zone Using TED
N

FIG. 2

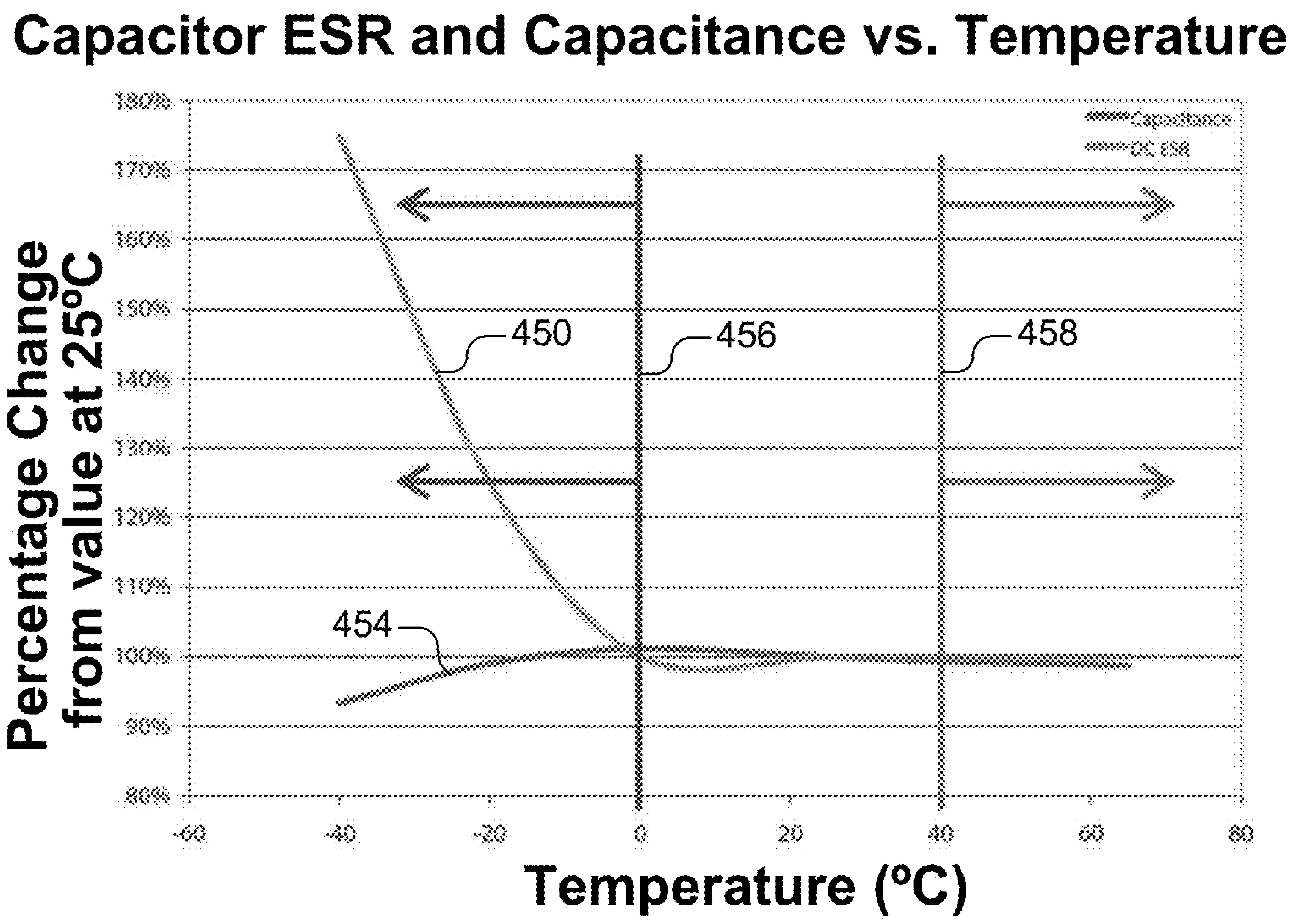
Capacitor ESR and Capacitance vs. Temperature
Capacitance
DC ESR
Percentage Change from value at 25°C
180%
170%
160%
150%
140%
130%
120%
110%
100%
90%
80%
-60
-40
-20
0
20
40
60
80
Temperature (°C)
450
456
458
454

FIG. 3

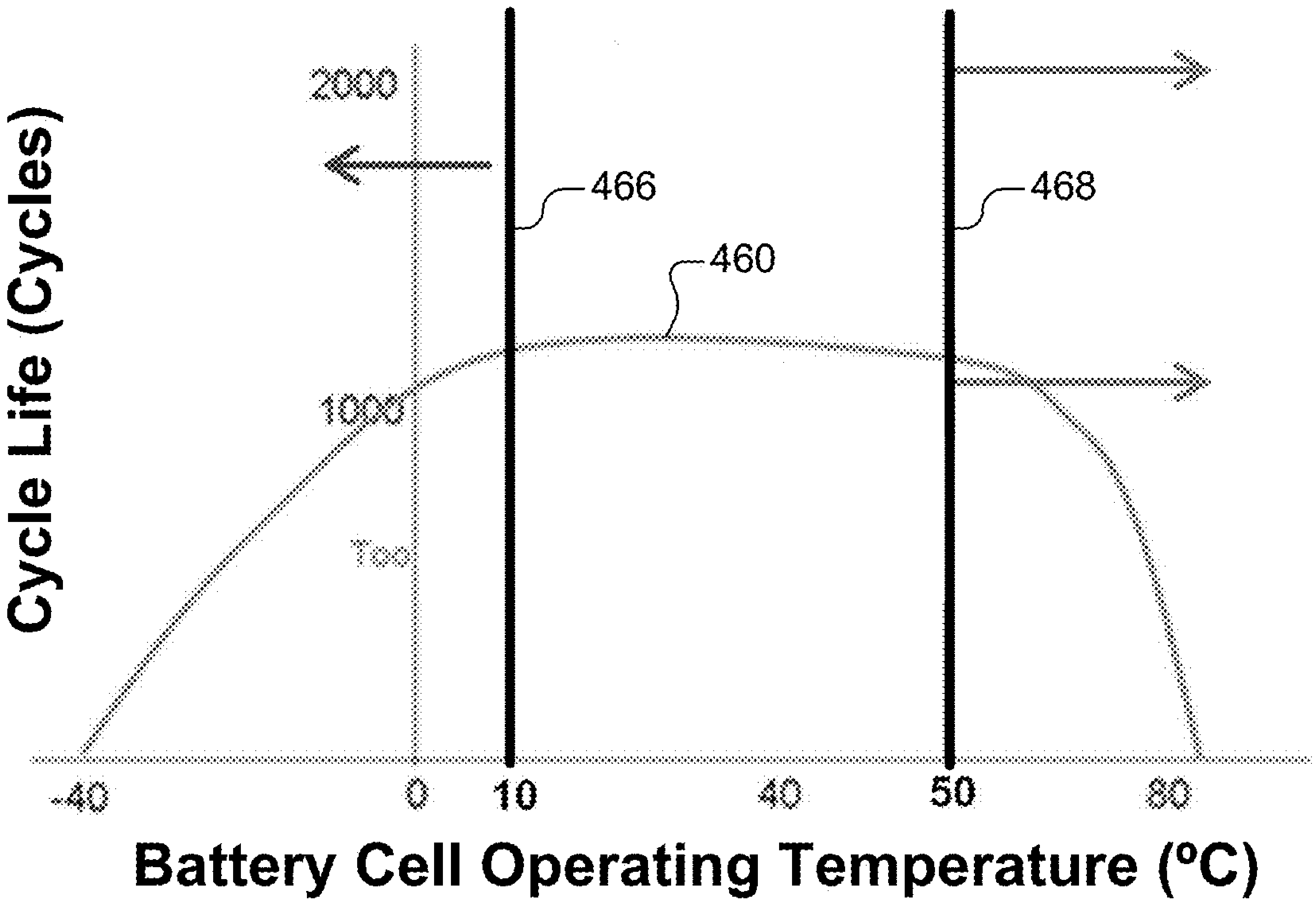
Cycle Life (Cycles)
2000
1000
Too
466
468
460
-40
0
10
40
50
80
Battery Cell Operating Temperature (°C)

FIG. 4

BATTERY AND CAPACITOR ASSEMBLY FOR A VEHICLE AND A METHOD FOR HEATING AND COOLING THE BATTERY AND CAPACITOR ASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATIONS

The present disclosure is a divisional of U.S. patent application Ser. No. 15/208,143 filed on Jul. 12, 2016, which claims the benefit of U.S. Provisional Application No. 62/302,386, filed on Mar. 2, 2016. The entire disclosures of these applications are incorporated herein by reference.

This application is related to U.S. Provisional Application No. 62/302,372, filed on Mar. 2, 2016, and U.S. application Ser. No. 15/208,112, filed on Jul. 12, 2016, and U.S. application Ser. No. 15/434,765, filed on Feb. 16, 2017. The entire disclosure of each of the above applications is incorporated herein by reference.

FIELD

The present disclosure relates to vehicle battery systems, and more particularly to battery and capacitor assemblies for a vehicle and methods for heating and cooling the battery and capacitor assemblies.

BACKGROUND

The background description provided here is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

Hybrid vehicles typically use a powertrain system including an engine, a stop-start or mild hybrid system including a starter/generator and/or one or more electric motors for propelling the vehicle. During operation, current needs to be supplied to start the engine, to supply loads connected to a vehicle power bus, to restart the engine, to drive the electric motors or starter/generator to move the vehicle and/or to recharge the batteries. For example in some mild hybrids, the electric motors or starter/generator drives the vehicle for brief periods such as 1-2 seconds during restarts to eliminate engine hesitation as the engine cranks, starts and reaches idle or other engine speed (hereinafter referred to as e-boost). As a result, significant engineering effort has been invested to improve the battery systems of hybrid vehicles to meet the increasing current loads.

The automotive industry has also proposed using batteries operating at higher voltage levels such as 24V, 36V and 48V and/or systems incorporating supercapacitors or ultracapacitors. However, these systems are fairly complex since they still need to operate with legacy 12V vehicle systems and components.

Some vehicle battery systems include a 12V battery (having a high capacity such as 100 Ah) in addition to a higher voltage battery, a supercapacitor or an ultracapacitor.

SUMMARY

In one example, the present disclosure describes a battery and capacitor assembly for a hybrid vehicle that includes a plurality of battery cells, a plurality of capacitor cells, a cooling plate, a pair of end brackets, and a housing. The plurality of capacitor cells are arranged adjacent to the plurality of battery cells such that the plurality of battery cells and the plurality of capacitor cells form a cell stack. The pair of end brackets are disposed at opposite ends of the cell stack and are attached to the cooling plate. The pair of end brackets compress the plurality of battery cells and the plurality of capacitor cells. The housing is attached to the cooling plate and encloses the cell stack and the pair of end brackets.

In one aspect, each of the plurality of battery cells and each of the plurality of capacitor cells has a pouch cell configuration. In another aspect, each of the plurality of battery cells is a lithium ion cell, and each of the capacitor cells is a supercapacitor cell and/or an ultracapacitor cell.

In other aspects, the battery and capacitor assembly further includes a pair of side brackets disposed on opposite sides of the cell stack and extending between the opposite ends of the cell stack. The side brackets are attached to the end brackets and cooperate with the end brackets to compress the plurality of battery cells and the plurality of capacitor cells.

In other aspects, the battery and capacitor assembly has a length extending between exterior end surfaces of the housing adjacent to the opposite ends of the cell stack, a width that extends between exterior side surfaces of the housing, and a height that extends between an exterior bottom surface of the housing and an exterior top surface of the cooling plate.

In one aspect, the width and/or length is less than or equal to 260 millimeters. In another aspect, the width is less than or equal to 200 millimeters and the height is less than or equal to 260 millimeters. In another aspect, the length is less than or equal to 400 millimeters.

In another aspect, the cooling plate defines a coolant channel for passing coolant through the cooling plate that absorbs heat from the cooling plate.

In another aspect, the battery and capacitor assembly further includes a plurality of heatsink plates disposed between adjacent ones of the plurality of battery cells and the plurality of capacitor cells and arranged to transfer heat to and from the cooling plate through conduction.

In another aspect, the battery and capacitor assembly further includes a plurality of thermoelectric devices disposed between the cooling plate and the cell stack and configured to adjust a temperature of the plurality of battery cells and adjust a temperature of the plurality of battery cells independent of adjusting the temperature of the plurality of battery cells.

In another aspect, at least one of the plurality of thermoelectric devices is disposed between the cooling plate and the plurality of battery cells, and at least one of the plurality of thermoelectric devices is disposed between the cooling plate and the plurality of capacitor cells.

In another aspect, the battery and capacitor assembly further includes a temperature distribution plate disposed between the plurality of thermoelectric devices and the cell stack and in contact with the cooling plate and/or the plurality of thermoelectric devices. The plurality of thermoelectric devices are in contact with the cooling plate.

In another aspect, each of the plurality of heatsink plates includes a plate-like body and a flange. The plate-like body is disposed between adjacent ones of the plurality of battery cells and the plurality of capacitor cells. The flange transfers heat to and from the temperature distribution plate through conduction using direct contact with the temperature distribution plate and/or a filler material disposed between the flange and the temperature distribution plate.

In another example, the present disclosure describes a battery and capacitor assembly for a hybrid vehicle that includes a plurality of battery cells, a plurality of capacitor cells, a cooling plate, and a plurality of thermoelectric devices. The plurality of capacitor cells are arranged adjacent to the plurality of battery cells such that the plurality of battery cells and the plurality of capacitor cells form a cell stack. The plurality of thermoelectric devices are disposed between the cooling plate and the cell stack. In addition, the plurality of thermoelectric devices are configured to heat and cool the plurality of battery cells and heat and cool the plurality of capacitor cells independent of heating and cooling the plurality of battery cells.

In one aspect, at least one of the plurality of thermoelectric devices is arranged to heat and cool the plurality of capacitor cells, and at least one of the plurality of thermoelectric devices is arranged to heat and cool the plurality of battery cells.

In another aspect, a single one of the plurality of thermoelectric devices is arranged to heat and cool the plurality of capacitor cells, and at least two of the plurality of thermoelectric devices are arranged to heat and cool the plurality of battery cells.

In another aspect, each of the plurality of thermoelectric devices is aligned with one of the plurality of battery cells and the plurality of capacitor cells which the thermoelectric device is configured to heat and cool.

In another aspect, the battery and capacitor assembly further includes a temperature distribution plate disposed between the plurality of thermoelectric devices and the cell stack and in contact with the cooling plate and/or the plurality of thermoelectric devices. The plurality of thermoelectric devices are in contact with the cooling plate.

In another aspect, the plurality of thermoelectric devices are disposed within pockets in the cooling plate, and the temperature distribution plate captures the plurality of thermoelectric devices within the pockets. In another aspect, the temperature distribution plate is partially inset in the cooling plate.

In another aspect, the battery and capacitor assembly further includes a plurality of heatsink plates disposed between adjacent ones of the plurality of battery cells and the plurality of capacitor cells. The plurality of heatsink plates are arranged to transfer heat to and from the temperature distribution plate through conduction.

In other aspects, each of the plurality of heatsink plates includes a plate-like body and a flange. The plate-like body is disposed between adjacent ones of the plurality of battery cells and the plurality of capacitor cells. The flange transfers heat to and from the temperature distribution plate through conduction using direct contact with the temperature distribution plate and/or a filler material disposed between the flange and the temperature distribution plate.

In another example, the present disclosure describes a system for controlling temperatures of a plurality of battery cells and a plurality of capacitor cells disposed within a common enclosure. The system includes a battery temperature sensor, a capacitor temperature sensor, and a control module. The battery temperature sensor measures the temperature of the plurality of battery cells. The capacitor temperature sensor measures the temperature of the plurality of capacitor cells. The control module controls an amount of current, voltage, and/or power supplied to a plurality of thermoelectric devices to heat and cool the plurality of battery cells based on the battery cell temperature. In addition, the control module controls the amount of current, voltage, and/or power supplied to the plurality of thermoelectric devices to heat and cool the plurality of capacitor cells based on the capacitor cell temperature and independent of heating and cooling the plurality of capacitor cells.

In one aspect, the control module controls the amount of current, voltage, and/or power supplied to a first one of the plurality of thermoelectric devices to one of heat and cool the plurality of battery cells, and controls the amount of current, voltage, and/or power supplied to a second one of the plurality of thermoelectric devices to one of heat and cool the plurality of battery cells.

In another aspect, the control module heats the plurality of battery cells when the battery cell temperature is less than a first temperature, cools the plurality of battery cells when the battery cell temperature is greater than a second temperature. In another aspect, the control module heats the plurality of capacitor cells when the capacitor cell temperature is less than a third temperature, and cools the plurality of capacitor cells when the capacitor cell temperature is greater than a fourth temperature.

In another aspect, the third temperature is different than the first temperature, and the fourth temperature is different than the second temperature. In another aspect, the third temperature is less than the first temperature, and the fourth temperature is less than the second temperature. In another aspect, each of the first, second, third, and fourth temperatures is predetermined.

In another aspect, the control module determines the first temperature based on a target resistance of the plurality of battery cells, a target amount of power supplied by the plurality of battery cells, and/or a target capacity of the plurality of battery cells. In another aspect, the control module determines the third temperature based on a target resistance of the plurality of capacitor cells, a target amount of power supplied by the plurality of capacitor cells, and/or a target capacity of the plurality of capacitor cells.

In another aspect, the control module heats the plurality of battery cells when the battery cell temperature is less than a first temperature if the plurality of battery cells are charging, and the control module does not heat the plurality of battery cells when the battery cell temperature is less than the first temperature if the plurality of battery cells are discharging.

In another example, the present disclosure describes a method for controlling temperatures of a plurality of battery cells and a plurality of capacitor cells disposed within a common enclosure. The method includes measuring the temperature of the plurality of battery cells, measuring the temperature of the plurality of capacitor cells, and controlling an amount of current, voltage, and/or power supplied to a plurality of thermoelectric devices to heat and cool the plurality of battery cells based on the battery cell temperature. The method further includes controlling the amount of current, voltage, and/or power supplied to the plurality of thermoelectric devices to heat and cool the plurality of capacitor cells based on the capacitor cell temperature and independent of heating and cooling the plurality of capacitor cells.

In another aspect, the method further includes controlling the amount of current, voltage, and/or power supplied to a first one of the plurality of thermoelectric devices to one of heat and cool the plurality of battery cells, and controlling the amount of current, voltage, and power supplied to a second one of the plurality of thermoelectric devices to one of heat and cool the plurality of battery cells.

In another aspect, the method further includes heating the plurality of battery cells when the battery cell temperature is less than a first temperature, and cooling the plurality of battery cells when the battery cell temperature is greater than a second temperature. In another aspect, the method further includes heating the plurality of capacitor cells when the capacitor cell temperature is less than a third temperature, and cooling the plurality of capacitor cells when the capacitor cell temperature is greater than a fourth temperature.

In another aspect, the third temperature is different than the first temperature, and the fourth temperature is different than the second temperature. In another aspect, the third temperature is less than the first temperature, and the fourth temperature is less than the second temperature. In another aspect, each of the first, second, third, and fourth temperatures is predetermined.

In another aspect, the method further includes determining the first temperature based on a target resistance of the plurality of battery cells, a target amount of power supplied by the plurality of battery cells, and/or a target capacity of the plurality of battery cells. In another aspect, the method further includes determining the third temperature based on a target resistance of the plurality of capacitor cells, a target amount of power supplied by the plurality of capacitor cells, and/or a target capacity of the plurality of capacitor cells.

In another aspect, the method further includes heating the plurality of battery cells when the battery cell temperature is less than a first temperature if the plurality of battery cells are charging, and not heating the plurality of battery cells when the battery cell temperature is less than the first temperature if the plurality of battery cells are discharging.

Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1**A is a functional block diagram of an example of a power management system for supplying power from and recharging of a battery and a capacitor according to the present disclosure;

FIG. **1**B is a more detailed functional block diagram of an example of a power management module in FIG. **1**A;

FIG. **1**C is a cross-sectional view of an integrated battery and capacitor assembly with heating and cooling capability according to the present disclosure;

FIG. **1**D is a cross-sectional view of a portion of the integrated battery and capacitor assembly of FIG. **1**C within a circle **1**D shown in FIG. **1**C;

FIG. **1**E is a partially exploded perspective view of the integrated battery and capacitor assembly of FIG. **1**C;

FIG. **1**F is an exploded front view of an example of a battery cell or a capacitor cell according to the present disclosure;

FIG. **2** is a flowchart illustrating an example of a method for controlling temperatures of the battery and the capacitor according to the present disclosure;

FIG. **3** is a graph illustrating DC equivalent series resistance (ESR) as a function of temperature for the capacitor; and

FIG. **4** is a graph illustrating cycle life as a function of cell operating temperature for the battery.

In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

In systems and methods for supplying power in a hybrid vehicle according to the present disclosure, higher current loads that occur during starting or e-boost events are predominantly supplied by a capacitor such as a supercapacitor or an ultracapacitor. Current is also supplied by a battery at a limited and controlled rate during these events. As a result, the capacity and physical size of the battery can be substantially reduced while keeping the discharge rate (or C-rate) of the battery to a reasonable level.

In conventional battery systems, cranking after a "key-on" event is solely supported by the battery. As a result, the battery needs to have a sufficient capacity and discharge rate. The discharge rate or C-rating is defined as a ratio of current/capacity. For example, a first battery can supply 850A and has a capacity of 100 Ah (C-rate of 850A/100 Ah=8.5). In contrast, a second battery can supply 850A and has a capacity of 17 Ah (C-rate of 850N17 Ah=50). While both batteries supply the same amount of current, the second battery will have a significantly shorter battery life than the first battery in similar applications. In other words, the C-rate of the battery directly affects battery life and higher C-rates correspond to shorter battery life.

Unlike other hybrid battery topologies, the battery used in the power management system according to the present disclosure does not independently support key-on engine starting. The main function of the battery is to directly support vehicle loads such as boardnet loads. The battery also supplies controlled and limited current flow to indirectly support key-on engine starts and hybrid drive cycle events such as engine re-starting and/or electric boost. The battery is also used to recharge the capacitor after cranking.

Power supplied during regenerative/engine braking is used to recharge the capacitor rather than the battery. Power from the capacitor is fed to the battery at a limited and controlled rate over time, which reduces battery peak charge loads. In the systems and methods described herein, battery requirements are driven by energy rather than voltage drop at cranking amps, which allows a smaller capacity battery to be used.

The present disclosure can also be configured to support pulse-type vehicle loads, such as electric turbo systems or electric active suspension systems, by selectively supplying current from the capacitor via an AC/DC converter and/or a starter generator controller. Having the capacitor supply the pulse-type vehicle loads improves battery life and minimizes the requirements, size and cost of the battery.

The specifications of the battery can be varied based on the severity of the hybrid drive cycle and pulse-type boardnet loads that are expected for a given application. In general, the battery requirements, size and cost will be lower than hybrid topologies where the battery directly or substantially contributes to the hybrid drive cycle.

The packaging cost of the battery and wiring are greatly reduced though integration of the battery into an integrated battery and capacitor assembly. Additional packaging details of the integrated battery and capacitor assembly can be found in U.S. Application No. 62/302,372, filed on Mar. 2, 2016, which is incorporated by reference in its entirety.

Referring now to FIG. **1**A, a power management system **100** for controlling the supply of power from and recharging of a battery **108** and a capacitor **110** is shown. In some examples, the battery includes a 12 V battery including multiple battery cells connected in series and/or parallel to positive and negative battery terminals. In some examples, the battery cells are made using lithium iron phosphate ($LiFePO_4$) chemistry. In other examples, the battery cells are made using lithium titanate ($Li_4Ti_5O_{12}$) (LTO) chemistry, other lithium ion chemistry, or other battery chemistry. In some examples, the battery **108** includes pouch cells arranged in a 4sNp configuration. In some examples, the battery **108** provides 12.8 V nominal (8.0V to 14.4 V) and has a capacity of 20 Ah/256 Wh. In other examples, the battery has a capacity less than or equal to 20 Ah and a C-rate less than or equal to 6.

In some examples, the capacitor **110** includes multiple capacitor cells connected in series and/or parallel to positive and negative capacitor terminals. In some examples, the capacitor **110** includes supercapacitors or ultracapacitors. In some examples, the capacitor **110** provides 12V, 24V, 36V, or 48V nominal (0-54 V). In some examples, a pouch cell format is used for capacitor cells in the capacitor. In some examples, the capacitors are connected in an 18sNp configuration and have a capacity of 0.6 Ah (30 Wh).

A power management module **112** controls the supply of power from and recharging of the battery **108** and the capacitor **110**. The power management module **112** may communicate over a vehicle data bus **114** with other vehicle controllers and/or with components of the power management system **100**. The power management module **112** may transmit data such as state of charge (SOC) and state of health (SOH) for the battery **108** and the capacitor **110** to other vehicle controllers. In some examples, the vehicle data bus **114** includes a CAN bus, although other data bus types can be used. In some examples, the power management module **112** receives information such as key-on events, vehicle speed, drive mode events, engine oil temperature, regeneration events, e-boost events or other control information from other vehicle controllers. Vehicle speed may be indicative of a future regeneration event. Engine oil temperature may be indicative of engine load during cranking. The power management module **112** may adjust operation of the power management system **100** based on these signals.

In some operating modes, the power management module also controls the supply of current to a vehicle power bus **102** and vehicle loads **104** such as boardnet loads. The power management module **112** receives battery operating parameters from one or more sensors such as temperature sensors **130** and/or voltage sensors **132**. In some examples, the temperature sensors **130** and the voltage sensors **132** monitor temperatures and voltages at the battery cell level. The power management module **112** also receives capacitor operating parameters from one or more sensors such as temperature sensors **136** and/or voltage sensors **138**. In some examples, the temperature sensors **136** and the voltage sensors **138** monitor temperatures and voltages at the capacitor cell level.

Temperature control of the battery **108** and/or the capacitor **110** may be provided by thermoelectric devices (TEDs) **140** and **142**, respectively. A TED driver circuit **146** controls the TEDs **140** and **142**. The power management module **112** selectively actuates the TED driver circuit **146** as needed to adjust the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** and thereby control the temperature of the battery **108** and the capacitor **110**. In some examples, the TEDs **140** and/or **142** include one or more heating/cooling zones that allow individual and independent temperature control of one or more battery cells or capacitor cells.

In some cases, when controlling the TEDs **140** and **142** to cool the battery **108** and/or the capacitor **110**, increasing the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** may increase the amount of cooling provided by the TEDs **140** and **142**. However, increasing the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** may also increase the amount of resistive heat provided by the TEDs **140** and **142**. Thus, in some cases, increasing the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** may decrease the overall cooling effect of the TEDs **140** and **142**. Therefore, the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** may be controlled based on a balance between the amount of cooling provided by the TEDs **140** and **142** and the amount of resistive heat provided by the TEDs **140** and **142**.

The power management module **112** may control the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** based on the aforementioned balance to achieve a maximum temperature difference across the TEDs **140** and **142**. The temperature difference across each of the TEDs **140** and **142** is an indicator of their respective overall cooling effects. In some examples, the power management module **112** controls the TEDs **140** and **142** in an open-loop manner based on a predetermined relationship between (1) the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** and (2) the temperature difference across the TEDs **140** and **142**. In some conditions, the power management module **112** adjusts or selects the predetermined relationship based on the age and/or temperature of the battery **108** and/or the capacitor **110**.

In some examples, the power management module **112** controls the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** in a closed-loop manner based on a measured temperature difference across the TEDs **140** and **142**. For example, the power management module **112** may adjust the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** to maximize their measured temperature differences and thereby maximize their cooling effects.

In contrast, when controlling the TEDs **140** and **142** to heat the battery **108** and/or the capacitor **110**, resistive heating adds to, rather than detracts from, the overall heating effect of the TEDs **140** and **142**. Thus, in some examples, the power management module **112** always increases the amount of current, voltage, and/or power supplied to the TEDs **140** and **142** to increase the amount of heat provided by the TEDs **140** and **142**.

A current detector circuit **150** detects current supplied by the battery or supplied to the battery during recharging. The current detector circuit **150** may be arranged between a negative terminal of the battery **108** and chassis ground **152**. A current detector circuit **156** detects current supplied by the capacitor **110** or supplied to the capacitor **110** during recharging. The current detector circuit **156** may be arranged between a negative terminal of the capacitor **110** and the chassis ground **152**. The current detector circuits **150** and **156** provide sensed battery current and capacitive current values, respectively, to the power management module **112**.

An overvoltage protection circuit **160** may be arranged between a positive terminal of the battery **108** and loads such as the vehicle power bus **102**. The overvoltage protection circuit **160** monitors a voltage output of the battery and provides a voltage value to the power management module **112**. The overvoltage circuit **160** protects the battery from overcharging when one or more cells is at or above a voltage limit of the battery cell. Another function of the overvoltage circuit **160** is to protect the battery from excessive current. If an over voltage condition is detected, the battery **108** may be disconnected or other actions may be taken. For example, excessive voltage or current may occur during charging with an external charger.

In some examples, the power management module **112** performs battery management including cell voltage measurement, cell balancing, temperature measurement, current limits calculations, state of charge (SOC) estimation and/or state of health (SOH) estimation based on the measured battery parameters. In some examples, the power management module **112** also performs capacitor management including cell voltage measurement, cell balancing, temperature measurement, current limits calculations, SOC estimation and/or SOH estimation based on measured capacitor parameters.

A DC/DC converter **161** may be provided to control flow of the current between the battery **108**, the capacitor **110** and/or a starter/generator **174**. In some examples, the DC/DC converter **161** includes a DC/DC boost converter **162** and a DC/DC buck converter **164** that are connected between the battery **108**, the capacitor **110** and the starter/generator **174**. In some examples, the DC/DC boost converter **162** has an input range of 8V to 16V and a current input range of 0-100 Amps. In some examples, the DC/DC boost converter **162** has an output range of 24V to 54V and a current output range of 0-67 Amps.

In some examples, the DC/DC buck converter **164** has an input range of 24V to 54V and a current input range of 0-53 Amps. In some examples, the DC/DC buck converter **164** has an output range of 8V to 16V and a current output range of 0-80 Amps. As can be appreciated, the ratings of the DC/DC boost converter **162** and the DC/DC buck converter **164** will vary for different applications.

A starter/generator controller **170** is connected to the DC/DC boost converter **162**, the DC/DC buck converter **164**, and the capacitor **110**. The starter/generator controller **170** is also connected to a DC/AC converter **172**, which is connected to the starter/generator **174**. The starter/generator **174** is connected to an engine (not shown). In some examples, one or more electric motors **175** for driving the wheels may be provided.

The vehicle power bus **102** may also be connected to an electric turbo **180** and/or an active suspension system **182**, which operate at the voltage of the battery **108**. Alternately, an electric turbo **184** and/or an active suspension system **186** may be connected to the starter/generator controller **170** and/or the DC/AC converter **172** if they operate at higher voltages such as 24V, 36V, 48V, etc.

In some examples, a key-on starter **176** may be connected to the starter/generator controller **170** and may be provided for starting larger displacement engines requiring higher starting current. The key-on starter **176** may be supplied by current from the capacitor **110** and assisted in a limited and controlled manner by current supplied by the battery **108** as described above.

Referring now to FIG. **1**B, an example of the power management module **112** is shown in further detail. The power management module **112** includes a battery monitoring module **192**, a capacitor monitoring module **194** and a control module **196**. The battery monitoring module **192** receives cell voltages, battery current, cell temperatures and/or string voltage as described above in FIG. **1**A. The battery monitoring module **192** performs cell balancing, calculates state of charge (SOC) and/or state of health (SOH) values for the battery **108**. The capacitor monitoring module **194** also receives cell voltages, capacitor current, cell temperatures and/or string voltage as described above in FIG. **1**A. The capacitor monitoring module performs cell balancing, calculates SOC and/or calculates SOH for the capacitor **110**.

The control module **196** communicates with the battery monitoring module **192** and the capacitor monitoring module **194**. The control module **196** may also receive information such as key-on events, vehicle speed, engine oil temperature, drive mode events, regeneration events, e-boost events or other control information from other vehicle controllers via the vehicle data bus **114**. The control module **196** may also share SOC and SOH values for the battery **108** and the capacitor **110** with other vehicle controllers via the vehicle data bus **114**.

The control module **196** enables and disables the DC/DC converter **161**. For example, the control module enables and disables the DC/DC buck converter **164** and the DC/DC boost converter **162** as needed during the various drive or operating modes. The control module **196** also monitors operation of the overvoltage protection circuit **160**. The control module **196** also communicates with the TED driver circuit **146** to control heating/cooling of zones in the TEDs **140** and **142** associated with the battery **108** and the capacitor **110**.

Referring now to FIGS. **1**C and **1**E, an example of a battery and capacitor assembly **200** is shown. The battery and capacitor assembly **200** includes the battery **108**, the capacitor **110**, and a cooling plate assembly **202**. The battery **108** and the capacitor **110** include cells **204** and **206**, respectively, that are arranged adjacent one another so as to form a cell stack **208**. Each of the cells **204** and/or **206** may be pouch-type cells.

The cells **204** and **206** have terminals or tabs **209** and **210**, respectively, for conducting current to and from the cells **204** and **206**. The tabs **209** and **210** extend from top surfaces **212** and **214**, respectively, of the cells **204** and **206**. In FIGS. **1**C and **1**E, the cells **204** and **206** are arranged with their side surfaces facing downward such that the tabs **209** and **210** extend toward a side **216** of the battery and capacitor assembly **200** shown in FIG. **1**E. Alternatively, the cells **204** and **206** may be arranged with their bottom surfaces facing upward such that the tabs **209** and **210** extend toward a bottom end **218** of the battery and capacitor assembly **200** shown in FIG. **1**C.

End brackets **220** are positioned at opposite ends **222** and **224** of the cell stack **208**, alongside outwardly-facing surfaces of outer ones of the cells **204** and **206**, such that the cells **204** and **206** are arranged between the end brackets **220**. In some examples, the end brackets **220** have a generally "L"-shaped cross section as shown in FIG. **1**C. In some examples, the end brackets **220** are made from metal (e.g., sheet metal). As shown in FIG. **1**E, each of the end brackets **220** may include a plate-like body **226** and a flange **228** extending from an end of the plate-like body **226** at an angle (e.g., 90 degrees) relative to the plate-like body **226**. The end brackets **220** are attached to the cooling plate assembly **202** by, for example, inserting a fastener through the flanges **228** of the end brackets **220** and into the cooling plate assembly **202**. The end brackets **220** provide a compressive force on the pouch-type capacitive and battery cells located therebetween during operation. In addition, the end brackets **220** secure the cell stack **208** to the cooling plate assembly **202**.

Side brackets **232** are positioned on opposite sides of the cell stack **208** and extend between the ends **222** and **224** of the cell stack **208**. In some examples, two side brackets may be position on each side of the cell stack **208**, yielding a total of four side brackets. In some examples, the side brackets **232** have a generally "C"-shaped cross section as shown in FIG. **1**E. In some examples, each of the side brackets **232** has a width Wb (FIG. **1**C) in a range from 0.25 inches to 0.75 inches (e.g., 0.5 inches). In some examples, the side brackets **232** are made from metal (e.g., sheet metal). During assembly, the end brackets **220** may be positioned at the ends **222** and **224** of the cell stack **208** and attached to the cooling plate assembly **202**. The end brackets **220** may be held in a position to apply a compressive force to the cell stack **208** using a compression fixture. The side brackets **232** may then be fit over and attached to the end brackets **220**, and the compression fixture may be removed. Thus, the side brackets **232** may cooperate with the end brackets **220** to compress the cells **204** and **206** in the cell stack **208**.

Heatsink plates **234** are arranged between the cells **204** and **206** to dissipate heat. In some examples, the heatsink plates **234** have a generally "L"-shaped cross section as shown in FIG. **1**C. In some examples, the heatsink plates **234** are made from metal (e.g., aluminum). As shown in FIG. **1**E, each of the heat sink plates **234** may include a plate-like body **236** and a flange **238** extending from the plate-like body **236** at an angle (e.g., 90 degrees) relative to the plate-like body **236**.

The flanges **238** of the heatsink plates **234** are in thermal contact with an outer bottom surface **230** of a temperature distribution plate **248** of the cooling plate assembly **202** so as to transfer heat to and from the temperature distribution plate **248** through conduction. For example, the flanges **238** of the heatsink plates **234** may directly contact the bottom surface **230**. Alternatively, with brief reference to FIG. **1**D, there may be a gap **240** between the flanges **238** and the bottom surface **230** to allow vertical movement of the heatsink plates **234**, and a filler material **242** may be disposed in the gap **240**. The filler material **242** may include grease, epoxy, foam, and/or another suitable type of material for transferring heat between the heat sink plates **234** and the cooling plate assembly **202** via conduction.

Referring again to FIGS. **1**C and **1**E, the cooling plate assembly **202** includes a cooling plate **244**, the TEDs **140** and **142**, and the temperature distribution plate **248**. In some examples, the cooling plate **244** is formed (e.g., cast or machined) from metal (e.g., aluminum). In some examples, the TEDs **140** and **142** are embedded in the cooling plate **244**, and the temperature distribution plate **248** captures the TEDs **140** and **142** within the cooling plate **244**. In some examples, the cooling plate **244** defines pockets or raised mounting areas, the TEDs **140** and **142** are positioned within the pockets or on the raised mounting areas, and the temperature distribution plate **248** is attached to the cooling plate **244** to capture the TEDs **140** and **142** within the pockets or raised mounting areas. In addition, the temperature distribution plate **248** may be partially inset in the cooling plate **244** and project from a bottom surface **252** thereof as shown in FIG. **1**C. Alternatively, the temperature distribution plate **248** may be completely proud of the cooling plate **244** on a raised mounting area on the cooling plate **244**.

The temperature distribution plate **248** dissipates or spreads out hot or cold spots along surfaces thereof to equalize temperature variation. In some examples, the temperature distribution plate **248** may also be split into zones with thermal separation therebetween so that the battery **108** and the capacitor **110** may be maintained at different temperatures. For example, the temperature distribution plate **248** may include a first plate positioned adjacent to the cells **204** of the battery **108**, and a second plate positioned adjacent to the cells **206** of the capacitor **110** and thermally insulated from the first plate. In some examples, the temperature distribution plate **248** is formed (e.g., stamped) from metal (e.g., aluminum).

The TEDs **140** and **142** are arranged in one or more heating/cooling zones to independently control the temperatures of the zones and/or of cells disposed therein. The zones may be thermally insulated from one another using, for example, an air gap disposed between the zones. In the example shown, the TED(s) **140** consists of a single TED arranged in a zone **108-1** of the battery **108**, and the TED(s) **142** includes TEDs **142-1**, **142-2**, **142-3**, and **142-4** arranged in zones **110-1**, **110-2**, **110-3**, and **110-4**, respectively, of the capacitor **110**. The TED(s) **140** is arranged to control the temperature(s) of the cells **204** of the battery **108** and/or the zone(s) in which the cells **204** are disposed. For example, the TED(s) **140** may be disposed above the cells **204**, adjacent to the cells **204**, and/or aligned with the cells **204** along a longitudinal axis **254** of the battery and capacitor assembly **200** shown in FIG. **1**C.

The TEDs **142-1** through **142-4** are arranged to control the temperature(s) of cells **206** of the capacitor **110** and/or the zone(s) in which the cells **204** are disposed. For example, the TEDs **142-1** through **142-4** may be disposed above the cells **206**, adjacent to the cells **206**, and/or aligned with the cells **206** along the longitudinal axis **254**. Thus, the TEDs **140** and **142** may be used to independently control the temperatures of the cells **204** and **206**, respectively. In some examples, multiple TEDs may be used in place of the TED(s) **140** to control the temperature(s) of the cells **204** of the battery **108**. In some examples, a single TED may be used in place of the TEDs **142-1** through **142-4** to control the temperature(s) of the cells **206** of the capacitor **110**.

The temperatures sensors **130** are arranged adjacent to the battery cells **204** to measure the temperature thereof. For example, the temperature sensors **130** may be positioned between the top surfaces **212** of the battery cells **204** and an interior surface of the side **216** of the battery and capacitor assembly **200** as shown in FIG. **1**E. In other examples, the temperature sensors **130** may be positioned in or on the TED(s) **140**, or on a busbar (not shown) that connects the tabs **209** of the battery cells **204** to each other. In some examples, the temperature sensors **130** may include a temperature sensor for each of the battery cells **204**. In some examples, a single temperature sensor may be used to measure the temperature of all of the battery cells **204**.

The temperatures sensors **136** are arranged adjacent to the capacitor cells **206** to measure the temperature thereof. For example, the temperature sensors **136** may be positioned between the top surfaces **214** of the capacitor cells **206** and the interior surface of the side **216** of the battery and capacitor assembly **200** as shown in FIG. **1**E. In other examples, the temperature sensors **130** may be positioned in or on one or more (e.g., all) of the TEDs **142-1** through **142-4**, or on a busbar (not shown) that connects the tabs **210** of the capacitor cells **206** to each other. In some examples, the temperature sensors **136** may include a temperature sensor for each of the capacitor cells **206**. In some examples, a single temperature sensor may be used to measure the temperature of all of the capacitor cells **206**.

In some examples, the temperature sensors **130** are arranged within one or more zones in which the battery cells **204** are disposed in order to measure the temperature(s) of the zones. In the example shown, the temperature sensors **130** are positioned within the zone **108-1** of the battery **108**. In some examples, the temperature sensors **136** are arranged within one or more zones in which the capacitor cells **206** are disposed in order to measure the temperature(s) of the zones. In the example shown, the temperature sensors **136** include temperature sensors **136-1**, **136-2**, **136-3**, and **136-4** that are arranged in the zones **110-1**, **110-2**, **110-3**, and **110-4**, respectively, of the capacitor **110**. In addition, a plurality (e.g., five) of the capacitor cells **206** are disposed in each of the zones **110-1** through **110-4**.

In some examples, the cooling plate **244** defines one or more coolant channels **256** through which coolant flows. Coolant flowing through the coolant channels **256** absorbs heat from the cooling plate **244**. As shown in FIG. **1**C, the coolant channels **256** have an inlet **256-1** and an outlet **256-2**. Coolant enters the coolant channels **256** through the inlet **256-1** and exits the coolant channels **256** through the outlet **256-2**.

In the example shown, the inlet **256-1** and the outlet **256-2** are disposed at opposite ends of the cooling plate **244**. Alternatively, the inlet **256-1** and the outlet **256-2** may be disposed on the same side of the cooling plate **244**. In addition, the coolant channels **256** may collectively form a generally "U"-shaped channel that extends from the inlet **256-1** to the outlet **256-2**, and cooling fins (not shown) may be disposed in the "U"-shaped channel. The cooling fins increase the amount of heat transfer between the cooling plate **244** and the coolant flowing through the coolant channels **256**, and may separate the coolant channels **256** while allowing coolant to flow therebetween.

In some examples, the DC/DC boost converter **162** and the DC/DC buck converter **164** are in thermal contact (or a heat exchange relationship) with an outer top surface **258** of the cooling plate assembly **202**. Likewise, the DC/AC converter **172** is also in thermal contact (or a heat exchange relationship) with the outer surface **258** of the cooling plate assembly **202**.

A housing **260** cooperates with the cooling plate **244** to completely enclose the cell stack **208**. As shown in FIG. **1**E, the housing **260** has a box shape with a closed bottom **262**, an open top **264**, and sides **266**, **268**, **270**, and **272**. The housing **260** may be attached to the cooling plate assembly **202** by, for example, inserting fasteners through the sides **266** and **270** of the housing **260** and into the cooling plate **244**, or inserting fasteners from a flange (not shown) located at the top of the sides **266**, **268**, **270**, and **272** into the cooling plate **244**. In some examples, the housing **260** is made from metal and/or plastic. In some examples, the power management module **112** is also disposed within the housing **260**.

The integration of the battery **108** and the capacitor **110** within a single housing is enabled by the smaller physical size of the battery **108** relative the physical size of a conventional hybrid battery. For example, whereas a conventional hybrid battery may have a physical size associated with a capacity of 100 Ah, the battery **108** may have a physical size associated with a capacity of 17 Ah. The smaller physical size of the battery **108** is enabled by primarily using the capacitor **110** and only indirectly using the battery **108** to support higher current loads that occur during starting or e-boost events, and by limiting the discharge rate (or C-rate) of the battery **108**. Additional power management details can be found in U.S. Application No. 62/302,372, filed on Mar. 2, 2016.

With continued reference to FIG. **1**E, the battery and capacitor assembly **200** has a length L, a width W, and a height H. The length L extends from an exterior surface of the side **266** of the housing **260** to an exterior surface of the side **270** of the housing **260**. The width W extends from an exterior surface of the side **268** of the housing **260** to an exterior surface of the side **272** of the housing **260**. The height H extends from an exterior surface of the bottom **262** of the housing **260** to a top surface **274** of the housing **260** and extends around the open top **264** of the housing **260**.

The dimensions of the battery and capacitor assembly **200** may be comparable to the dimensions of a conventional lead acid battery. For example, the width W may be less than or equal to 200 millimeters (mm), the height H may be less than or equal to 260 mm, and the length L may be less than or equal to 400 mm. In some examples, the width W may be in a range from 170 mm to 200 mm, the height H may be in a range from 200 mm to 260 mm, and the length L may be in a range from 300 mm to 400 mm.

The aforementioned dimensions may apply when the cells **204** and **206** are arranged with their side surfaces facing downward as shown in FIGS. **1**C and **1**E. Thus, if the cells **204** and **206** are arranged with their bottom surfaces facing downward, the numerical ranges for the width W and the height H may be reversed. For example, the width W may be in a range from 200 mm to 260 mm, the height H may be in a range from 170 mm to 200 mm.

The dimensions of the battery and capacitor assembly **200** may be quantified relative to the dimensions of the cells **204** and **206** of the battery **108** and the capacitor **110**, respectively. For example, each of the cells **204** and **206** may have dimensions D**1**, D**2**, and D**3** aligned with the width W, the height H, and the length L, respectively, of the battery and capacitor assembly **200**. The dimension D1 may be in a range from 120 mm to 140 mm (e.g., 130 mm), the dimension D2 may be in a range from 145 mm to 165 mm (e.g., 140 mm), and a sum of the dimension D3 for all of the cells **204** and **206** may be in a range from 240 mm to 260 mm (e.g., 250 mm).

The width W of the battery and capacitor assembly **200** may be greater than the dimension D**1** of each of the cells **204** and **206** by an amount in a range from 50 percent to 60 percent (e.g., 54 percent). The amount by which the width W is greater than the dimension D**1** may provide clearance for a thickness T of the housing **260** and for the tabs **209** and **210** of the cells **204** and **206**, respectively. In addition, the power management module **112** may be positioned between (1) the tabs **209** and **210** and (2) the housing **260**, and the amount by which the width W is greater than the dimension D1 may provide clearance for the power management module **112**.

The height H of the battery and capacitor assembly **200** may be greater than the dimension D**2** of each of the cells **204** and **206** by an amount in a range from 10 percent to 20 percent (e.g., 12 percent). The amount by which the height H is greater than the dimension D2 may provide clearance for the thickness T of the housing **260**. The length L of the battery and capacitor assembly **200** may be greater than a sum of the dimension D3 for all of the cells **204** and **206** by an amount in a range from 15 percent to 25 percent (e.g., 20 percent). The amount by which the length L is greater than the dimension D3 may provide clearance for the thickness T of the housing **260**, for the end brackets **220**, and for the tolerance stack-up of the cells **204** and **206**.

The dimension D1 of the cells **204** and **206** may be aligned with the width W and the dimension D2 may be aligned with the height H when the cells **204** and **206** are arranged with their side surfaces facing downward as shown in FIGS. **1**C and **1**E. In contrast, if the cells **204** and **206** are arranged with their bottom surfaces facing downward, the dimension D1 of the cells **204** and **206** may be aligned with the height H and the dimension D2 may be aligned with the width W. In this case, dimension D1 may be in a range from 145 mm to 165 mm (e.g., 140 mm), and the dimension D2 may be in a range from 120 mm to 140 mm (e.g., 130 mm). In addition, the width W may be greater than the dimension D2 of each of the cells **204** and **206** by an amount in a range from 10 percent to 20 percent (e.g., 12 percent). In addition, the height H may be greater than the dimension D1 of each of the cells **204** and **206** by an amount in a range from 50 percent to 60 percent (e.g., 54 percent).

Referring now to FIG. **1**F, an example of a cell **300** having a pouch configuration is shown. The cell **300** may be representative of one of the cells **204** of the battery **108** and/or one of the cells **206** of the capacitor **110**. The cell **300** includes a housing **302**, first electrodes (e.g., cathodes) **304**, second electrodes (e.g., anodes) **306** and separators **308** disposed adjacent ones of the first and second electrodes **304** and **306**.

The housing **302** includes a first side **310** and a second side **312**. During assembly, the electrodes **304** and **306** and the separators **308** may be positioned between the first and second sides **310** and **312**, and the first and second sides **310** and **312** may be joined together along seams **314**. In turn, the electrodes **304** and **306** and the separators **308** may be sealed within the housing **302**. In some examples, the housing **302** is made from plastic, and the first and second sides **310** and **312** are jointed together along the seams **314** using adhesive and/or heat sealing.

Each of the electrodes **304** includes plate-like body **316** and a tab **318** extending from one end of the plate-like body **316**. Similarly, each of the electrodes **306** includes plate-like body **320** and a tab **322** extending from one end of the plate-like body **320**. The tabs **318** of the electrodes **304** may cooperate to form one of the tabs **209** or **210** of the cells **204** or **206**, and the tabs **322** of the electrodes **306** may cooperate to form the other one of the tabs **209** or **210** on the same one of the cells **204** or **206**.

If the cell **300** is a lithium ion battery cell, the electrodes **304** and **306** may be coated with lithium iron phosphate ($LiFePO_4$), lithium titanate ($Li_4Ti_5O_{12}$) (LTO), and/or other lithium ion chemistry or battery chemistry. In addition, the cell **300** may store energy electrochemically. If the cell **300** is a supercapacitor (or ultracapacitor) cell, the electrodes **304** and **306** may be made from or coated with activated carbon (AC), carbon fiber-cloth (AFC), carbide-derived carbon (CDC), carbon aerogel, graphite, graphene, graphane, carbon nanotubes (CNTs) and/or other supercapacitor chemistry. In addition, the cell **300** may store energy electrostatically on the surfaces of the electrodes **304** and **306**, and the energy storage of the cell **300** may not involve chemical reactions.

When the cell **300** discharges, energy-containing ions travel from one of the electrodes **304** or **306**, through the one of separators **308**, and to the other one of the electrodes **304** or **306**. The movement of the ions releases energy, which may be extracted into an external circuit. When the cell **300** charges, energy is used to move the ions back to the one of the electrodes **304** or **306** from which the lithium ions travelled. The separators **308** are formed from an electrically insulating material so that the separators **308** electrically insulate the electrodes **304** and **306** from one another.

Referring now to FIG. **2**, a method **350** for controlling the temperature of the battery **108** and the capacitor **110** during operation is shown. The method **350** is described in the context of the modules included in the example implementation of the power management module **112** shown in FIG. **1**B. However, the particular modules that perform the steps of the method may be different than the modules mentioned below and/or the method may be implemented apart from the modules of FIG. **1**B.

At **360**, the control module **196** determines whether the key is on. When 360 is true, the control module **196** monitors the temperature of the battery cells **204** individually or monitors the temperature of one or more zones in which the battery cells **204** are disposed. In some examples, the control module **196** monitors the battery cell or zone temperature using the temperature sensors **130**. At **368**, the control module **196** determines whether the battery cell or zone temperature is less than a first temperature T**1**. If **368** is true, the control module **196** heats the corresponding battery cell or zone using the TED(s) **140**. For example, the control module **196** may heat the battery cells **204** disposed in the zone **108-1** when the temperature(s) measured by the temperature sensors **130** is less than the first temperature T**1**.

If **368** is false, the control module **196** continues at **376** and determines whether the battery cell or zone temperature is greater than a second temperature T**2**. If **376** is true, the control module **196** cools the corresponding battery cell or zone using the TED(s) **140**. For example, the control module **196** may cool the battery cells **204** disposed in the zone **108-1** when the temperature(s) measured by the temperature sensors **130** is greater than the second temperature T**2**.

The control module **196** continues from **372**, **376** or **378** and monitors a temperature of capacitor cells **206** individually or monitors the temperature of one or more zones in which the capacitor cells **206** are disposed. In some examples, the control module **196** monitors the capacitor cell or zone temperature using the temperature sensors **136**. At **384**, the control module **196** determines whether the capacitor cell or zone temperature is less than a third temperature T**3**. If **384** is true, the control module **196** continues at **338** and heats the corresponding capacitor cell or zone using the TED(s) **142**. For example, the control module **196** may heat the capacitor cells **206** disposed in the zone **110-1** when the temperature measured by the temperature sensor **136-1** is less the third temperature T**3**. Similarly, the control module **196** may heat the capacitor cells **206** disposed in the zones **110-2**, **110-3**, or **110-4** when the temperature measured by the temperature sensors **136-2**, **136-3**, or **136-4**, respectively, is less the third temperature T**3**.

If **384** is false, the control module **196** continues at **390** and determines whether the capacitor cell or zone temperature is greater than a fourth temperature T**4**. If **390** is true, the control module **196** continues at **396** and cools the corresponding battery cell or zone using the TED(s) **142**. For example, the control module **196** may cool the capacitor cells **206** disposed in the zone **110-1** when the temperature measured by the temperature sensor **136-1** is greater than the fourth temperature T**4**. Similarly, the control module **196** may heat the capacitor cells **206** disposed in the zones **110-2**, **110-3**, or **110-4** when the temperature measured by the temperature sensors **136-2**, **136-3**, or **136-4**, respectively, is greater than the fourth temperature T**4**.

In some examples, if the battery cell temperature is less than the first temperature, the control module **196** determines whether to heat the corresponding battery cell or zone based on whether the battery **108** is charging or discharging. If the battery cell temperature is less than the first temperature when the battery **108** is charging, the control module **196** heats the corresponding battery cell or zone. If the battery cell temperature is less than the first temperature when the battery **108** is discharging, the control module **196** does not heat the corresponding battery cell or zone.

Referring now to FIG. **3**, DC equivalent series resistance (ESR) is shown at **450** and capacitance is shown at **454** as a function of temperature for the capacitor **110**. Heating of the capacitor **110** above the third temperature T**3** (at **456**) is performed to reduce ESR at low temperatures to ensure high power and high capacity. This may be important for high power loads such as cold starting and e-boost. Cooling of the capacitor **110** below the fourth temperature T**4** (at **458**) is performed to improve capacitor cell life.

Referring now to FIG. **4**, cycle life is shown at **460** as a function of cell operating temperature for the battery **108**. Heating of the cells in the battery above the first temperature T**1** (at **466**) is performed to ensure low resistance, high power, full capacity, and long life. This may be important for high power loads such as cold starting. Cooling of the battery cells below the second temperature T**2** (at **468**) is performed to improve battery cell life.

In some examples, the first temperature T**1** for the battery cells is different than the third temperature T**3** for the capacitor cells and/or the second temperature T**2** for the battery cells is different than the fourth temperature T**4** for the capacitor cells. Since the TEDs are arranged in zones, different temperature ranges may be used to heat and cool the battery cells relative to the capacitor cells even though the battery cells and capacitor cells are arranged in the common assembly described above. In other examples, the first temperature T**1** for the battery cells is the same as the third temperature T**3** for the capacitor cells and/or the second temperature T**2** for the battery cells is the same as the fourth temperature T**4** for the capacitor cells.

For example, the first temperature T**1** may be in a range from 5° C. to 15° C., the second temperature may be in a range from 45° C. to 55° C., the third temperature T**3** may be in a range from −5° C. to 5° C., and the fourth temperature T**4** may be in a range from 35° C. to 45° C., although other temperatures may be used. In another example, the first temperature T**1** may be 10° C., the second temperature T**2** may be 50° C., the third temperature T**3** may be 0° C., and the fourth temperature may be 40° C.

In some examples, the first, second, third, and/or fourth temperatures T**1**, T**2**, T**3**, and/or T**4** are predetermined. In some examples, the control module **196** determines the first temperature T**1** and/or the second temperature T**2** based on a target resistance of the battery cells **204**, a target amount of power supplied by the battery cells **204**, a target capacity of the battery cells **204**, and/or a target life of the battery cells **204**. In some examples, the control module **196** determines the third temperature T**1** and/or the fourth temperature T**4** based on a target resistance of the capacitor cells **206**, a target amount of power supplied by the capacitor cells **206**, a target capacity of the capacitor cells **206**, and/or a target life of the capacitor cells **206**.

In one example, the capacity of the battery cells **204** may decrease at temperatures below 20° C., and the battery cells **204** may incur irreversible damage when the battery cells **204** are charged at temperatures below −20° C. Thus, the control module **196** may set the temperature T**1** to 20° C. when full battery capacity is desired. Otherwise, the control module **196** may set the temperature T**1** to −20° C.

In one example, the control module **196** may determine the second temperature T**2** based on a balance between the target amount of power supplied by the battery cells **204** and the target life of the battery cells **204**. For example, the second temperature T**2** may normally be a temperature (e.g., 50° C.) above which the life of the battery cells **204** decreases rapidly. However, if maximum battery power is desired, the control module **196** may temporarily adjust the second temperature T**2** to a higher temperature (e.g., 60° C.).

The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure. Further, although each of the embodiments is described above as having certain features, any one or more of those features described with respect to any embodiment of the disclosure can be implemented in and/or combined with features of any of the other embodiments, even if that combination is not explicitly described. In other words, the described embodiments are not mutually exclusive, and permutations of one or more embodiments with one another remain within the scope of this disclosure.

As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean "at least one of A, at least one of B, and at least one of C." Spatial and functional relationships between elements (for example, between modules, circuit elements, semiconductor layers, etc.) are described using various terms such as "connected," "adjacent," "next to," "on top of," "inner," "outer," "beneath," "below," "lower," "above," "upper," "bottom," "top," "side," and "disposed." Unless explicitly described as being "direct," when a relationship between first and second elements is described in the above disclosure, that relationship can be a direct relationship where no other intervening elements are present between the first and second elements, but can also be an indirect relationship where one or more intervening elements are present (either spatially or functionally) between the first and second elements.

In addition, spatially relative terms may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

In this application, including the definitions below, the term "module" or the term "controller" may be replaced with the term "circuit." The term "module" may refer to, be part of, or include: an Application Specific Integrated Circuit (ASIC); a digital, analog, or mixed analog/digital discrete circuit; a digital, analog, or mixed analog/digital integrated circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor circuit (shared, dedicated, or group) that executes code; a memory circuit (shared, dedicated, or group) that stores code executed by the processor circuit; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip.

The module may include one or more interface circuits. In some examples, the interface circuits may include wired or wireless interfaces that are connected to a local area network (LAN), the Internet, a wide area network (WAN), or combinations thereof. The functionality of any given module of the present disclosure may be distributed among multiple modules that are connected via interface circuits. For example, multiple modules may allow load balancing. In a further example, a server (also known as remote, or cloud) module may accomplish some functionality on behalf of a client module.

The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, data structures, and/or objects. The term shared processor circuit encompasses a single processor circuit that executes some or all code from multiple modules. The term group processor circuit encompasses a processor circuit that, in combination with additional processor circuits, executes some or all code from one or more modules. References to multiple processor circuits encompass multiple processor circuits on discrete dies, multiple processor circuits on a single die, multiple cores of a single processor circuit, multiple threads of a single processor circuit, or a combination of the above. The term shared memory circuit encompasses a single memory circuit that stores some or all code from multiple modules. The term group memory circuit encompasses a memory circuit that, in combination with additional memories, stores some or all code from one or more modules.

The term memory circuit is a subset of the term computer-readable medium. The term computer-readable medium, as used herein, does not encompass transitory electrical or electromagnetic signals propagating through a medium (such as on a carrier wave); the term computer-readable medium may therefore be considered tangible and non-transitory. Non-limiting examples of a non-transitory, tangible computer-readable medium are nonvolatile memory circuits (such as a flash memory circuit, an erasable programmable read-only memory circuit, or a mask read-only memory circuit), volatile memory circuits (such as a static random access memory circuit or a dynamic random access memory circuit), magnetic storage media (such as an analog or digital magnetic tape or a hard disk drive), and optical storage media (such as a CD, a DVD, or a Blu-ray Disc).

The apparatuses and methods described in this application may be partially or fully implemented by a special purpose computer created by configuring a general purpose computer to execute one or more particular functions embodied in computer programs. The functional blocks, flowchart components, and other elements described above serve as software specifications, which can be translated into the computer programs by the routine work of a skilled technician or programmer.

The computer programs include processor-executable instructions that are stored on at least one non-transitory, tangible computer-readable medium. The computer programs may also include or rely on stored data. The computer programs may encompass a basic input/output system (BIOS) that interacts with hardware of the special purpose computer, device drivers that interact with particular devices of the special purpose computer, one or more operating systems, user applications, background services, background applications, etc.

The computer programs may include: (i) descriptive text to be parsed, such as HTML (hypertext markup language) or XML (extensible markup language), (ii) assembly code, (iii) object code generated from source code by a compiler, (iv) source code for execution by an interpreter, (v) source code for compilation and execution by a just-in-time compiler, etc. As examples only, source code may be written using syntax from languages including C, C++, C#, Objective C, Haskell, Go, SQL, R, Lisp, Java®, Fortran, Perl, Pascal, Curl, OCaml, Javascript®, HTML5, Ada, ASP (active server pages), PHP, Scala, Eiffel, Smalltalk, Erlang, Ruby, Flash®, Visual Basic®, Lua, and Python®.

None of the elements recited in the claims are intended to be a means-plus-function element within the meaning of 35 U.S.C. § 112(f) unless an element is expressly recited using the phrase "means for," or in the case of a method claim using the phrases "operation for" or "step for."

What is claimed is:

1. A battery and capacitor assembly for a hybrid vehicle, comprising:

a plurality of battery cells;

a plurality of capacitor cells arranged adjacent to the plurality of battery cells such that the plurality of battery cells and the plurality of capacitor cells form a cell stack;

a cooling plate;

a pair of end brackets disposed at opposite ends of the cell stack and attached to the cooling plate, the pair of end brackets compressing the plurality of battery cells and the plurality of capacitor cells;

a housing attached to the cooling plate and enclosing the cell stack and the pair of end brackets; and

a plurality of thermoelectric devices disposed between the cooling plate and the cell stack and configured to adjust a temperature of the plurality of battery cells and adjust a temperature of the plurality of capacitor cells independent of adjusting the temperature of the plurality of battery cells.

2. The battery and capacitor assembly of claim **1**, wherein each of the plurality of battery cells and each of the plurality of capacitor cells has a pouch cell configuration.

3. The battery and capacitor assembly of claim **2**, wherein each of the plurality of battery cells is a lithium ion cell, and each of the capacitor cells is at least one of a supercapacitor cell and an ultracapacitor cell.

4. The battery and capacitor assembly of claim **1**, further comprising a pair of side brackets disposed on opposite sides of the cell stack and extending between the opposite ends of the cell stack, wherein the pair of side brackets is attached to the pair of end brackets and cooperate with the pair of end brackets to compress the plurality of battery cells and the plurality of capacitor cells.

5. The battery and capacitor assembly of claim **1**, wherein:

the battery and capacitor assembly has a length extending between exterior end surfaces of the housing adjacent to the opposite ends of the cell stack, a width that extends between exterior side surfaces of the housing, and a height that extends between an exterior bottom surface of the housing and an exterior top surface of the cooling plate; and

at least one of the width and length is less than or equal to 260 millimeters.

6. The battery and capacitor assembly of claim **5**, wherein the width is less than or equal to 200 millimeters and the height is less than or equal to 260 millimeters.

7. The battery and capacitor assembly of claim **6**, wherein the length is less than or equal to 400 millimeters.

8. The battery and capacitor assembly of claim **1**, wherein the cooling plate defines a coolant channel for passing coolant through the cooling plate that absorbs heat from the cooling plate.

9. The battery and capacitor assembly of claim **1**, further comprising a plurality of heatsink plates disposed between adjacent ones of the plurality of battery cells and the plurality of capacitor cells and arranged to transfer heat to and from the cooling plate through conduction.

10. The battery and capacitor assembly of claim **9**, further comprising a temperature distribution plate disposed between the plurality of thermoelectric devices and the cell stack and in contact with at least one of the cooling plate and the plurality of thermoelectric devices, wherein the plurality of thermoelectric devices are in contact with the cooling plate.

11. The battery and capacitor assembly of claim **10**, wherein each of the plurality of heatsink plates includes a plate-like body disposed between adjacent ones of the plurality of battery cells and the plurality of capacitor cells, and a flange that transfers heat to and from the temperature distribution plate through conduction using at least one of:

direct contact with the temperature distribution plate; and

a filler material disposed between the flange and the temperature distribution plate.

12. The battery and capacitor assembly of claim **1**, wherein:

at least one of the plurality of thermoelectric devices is disposed between the cooling plate and the plurality of battery cells; and

at least one of the plurality of thermoelectric devices is disposed between the cooling plate and the plurality of capacitor cells.

13. The battery and capacitor assembly of claim **1**, wherein:

the plurality of battery cells are disposed in a first zone; and

the plurality of capacitor cells are disposed in a second zone.

14. The battery and capacitor assembly of claim **13**, wherein:

at least one of the plurality of thermoelectric devices is arranged in the first zone; and

at least one of the plurality of thermoelectric devices is arranged in the second zone.

15. The battery and capacitor assembly of claim **1**, wherein the plurality of thermoelectric devices are configured to:

adjust the temperature of the plurality of battery cells independent of adjusting the temperature of all the plurality of capacitor cells in the battery and capacitor assembly; and

adjust the temperature of the plurality of capacitor cells independent of adjusting the temperature of all the plurality of battery cells in the battery and capacitor assembly.

16. A battery and capacitor assembly for a hybrid vehicle, comprising:

a plurality of battery cells;

a plurality of capacitor cells arranged adjacent to the plurality of battery cells such that the plurality of battery cells and the plurality of capacitor cells form a cell stack;

a cooling plate; and

a plurality of thermoelectric devices disposed between the cooling plate and the cell stack and configured to heat and cool the plurality of battery cells and heat and cool the plurality of capacitor cells independent of heating and cooling the plurality of battery cells.

17. The battery and capacitor assembly of claim **16**, wherein:

the plurality of battery cells are disposed in a first zone; and

the plurality of capacitor cells are disposed in a second zone.

18. The battery and capacitor assembly of claim **17**, wherein:

at least one of the plurality of thermoelectric devices is arranged in the second zone to heat and cool the plurality of capacitor cells; and

at least one of the plurality of thermoelectric devices is arranged in the first zone to heat and cool the plurality of battery cells.

19. The battery and capacitor assembly of claim **18**, wherein:

a single one of the plurality of thermoelectric devices is arranged in the second zone to heat and cool the plurality of capacitor cells; and

at least two of the plurality of thermoelectric devices are arranged in the first zone to heat and cool the plurality of battery cells.

20. The battery and capacitor assembly of claim **18**, wherein each of the plurality of thermoelectric devices is aligned with one of the plurality of battery cells and the plurality of capacitor cells which the thermoelectric devices are configured to heat and cool.

21. The battery and capacitor assembly of claim **16**, further comprising a temperature distribution plate disposed between the plurality of thermoelectric devices and the cell stack and in contact with at least one of the cooling plate and the plurality of thermoelectric devices, wherein the plurality of thermoelectric devices are in contact with the cooling plate.

22. The battery and capacitor assembly of claim **21**, wherein the plurality of thermoelectric devices are disposed within pockets in the cooling plate, and the temperature distribution plate captures the plurality of thermoelectric devices within the pockets.

23. The battery and capacitor assembly of claim **22**, wherein the temperature distribution plate is partially inset in the cooling plate.

24. The battery and capacitor assembly of claim **21**, further comprising a plurality of heatsink plates disposed between adjacent ones of the plurality of battery cells and the plurality of capacitor cells and arranged to transfer heat to and from the temperature distribution plate through conduction.

25. The battery and capacitor assembly of claim **24**, wherein each of the plurality of heatsink plates includes a plate-like body disposed between adjacent ones of the plurality of battery cells and the plurality of capacitor cells, and a flange that transfers heat to and from the temperature distribution plate through conduction using at least one of:

direct contact with the temperature distribution plate; and

a filler material disposed between the flange and the temperature distribution plate.

26. The battery and capacitor assembly of claim **16**, wherein the plurality of thermoelectric devices are configured to:

heat and cool the plurality of battery cells independent of heating and cooling the plurality of capacitor cells in the battery and capacitor assembly; and

heat and cool the plurality of capacitor cells independent of heating and cooling all the plurality of battery cells in the battery and capacitor assembly.

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